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Disturbance Effects of Auger-Stirring Corn

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ABSTRACT

INVESTIGATIONS were carried out studying disturbance effects of auger-stirring 11.3 percent moisture corn with a 51-mm (2-in.) diameter stirring auger. Bulk density effects and the shape of the disturbed volume were defined for auger travel rates from 0 to 10.3 mm/s (24.3 in./min). Kernel orientations inside and outside the disturbed region were compared.

Auger stirring devices are in wide use in bin-type corn-drying systems. These devices typically consist of one or more open 51-mm (2-in.) diameter, right-hand augers suspended from the bin roof and widewall and extending to near the bin floor. The augers rotate clockwise (viewed from above) and simultaneously travel horizontally. They lift grain from near the bin floor toward the top of the grain mass. H. A. Kalke of Rockford, Iowa was issued United States patent 3,156,541 for an auger stirring apparatus he invented during 1959-61. An auger stirring device was first commercially marketed in 1962. (Murphy, David M., 1977. Personal communication. David Manufacturing Co., Mason City, IA.)

Auger stirrers are used with two kinds of bin-drying systems: the in-storage layer-fill system, in which corn is dried and stored in the same bin to a depth of 5 to 6 m (16 to 20 ft), and the bin-batch system, in which corn is placed for drying and cooling and then is removed to storage. In both these systems, the stirrer offers significant management advantages.

A stirrer in an in-storage layer system allows the use of air temperatures as high as 60 °C (140 °F) resulting in faster drying and faster filling. If a stirring device is not used, an air temperature rise greater than about 11°C (20 °F) may result in moisture contents of less than 10 percent in the bottom layers of corn.

Use of a stirrer with a bin-batch system permits doubling of the normal 0.75 to 1.2-m (2.5 to 4-ft) grain depth without an excessive moisture content variation from bottom to top at the completion of drying (Brooker et al., 1974).

Two prior studies dealt with disturbance effects of auger stirring. Toms(1968) pictorially defined the region disturbed by a stirring auger as it rotated without horizontal movement in a plexiglas-windowed box with a horizontal cross-section 100 mm by 1.8 m (4 in. by 6 ft), containing corn to a depth of 1.8 m (6 ft). After about 15 min of operation, the disturbed region assumed a constant volume having a top width of 790 to 960 mm (31 to 38 in.) and a bottom width of 150 mm (6 in.). This volume appeared thoroughly mixed.

Hall and Beaty (1970) studied the mixing action of a stirring auger on wheat in a model bin at various horizontal travel rates and rotational speeds. For thorough blending of the 305-mm (12-in.) grain depth, traverse paths of the auger had to be adjacent, or spaced apart and repeated several times. Blending effectiveness improved as rotational speed increased and as horizontal travel rate decreased.

This paper reports on a study undertaken to define the boundaries of the region disturbed by a moving stirring auger and to investigate effects of auger-stirring on corn bulk density and kernel orientation (Bern, 1973).

EQUIPMENT AND METHODS

An apparatus was constructed that permitted moving a rotating auger through corn at various horizontal travel rates. A plywood bin 1010 mm (40 in.) long by 610 mm (24 in.) wide by 760 mm (30 in.) deep was mounted on a wheeled cart, which was pulled by a variable-speed winch. A stirring auger assembly was mounted overhead with provision for raising and lowering the auger. The 51-mm (2-in.) diameter right-hand stirring auger was lowered into the grain near one end of the bin. With the auger turning clockwise (when viewed from above) at 480 rpm, the bin was pulled by the winch until the stirring auger made contact with the opposite end. The stirring auger was then raised out of the corn. Horizontal travel rates of 0, 1.84, 3.69, 5.19, and 10.3 mm/s (0, 4.35, 8.71, 12.26, and 24.30 in./min) were used. For tests at zero travel rate, the auger was lowered and raised at a point halfway between the bin ends.

The grain was smoothed to a constant depth before and after stirring to permit accurate volume measurements. For each test, the bin was loaded by dropping the grain an average of 2.1 m (7 ft) from a hopper at a rate of approximately 2.3 kg/s (300 lb/min). The grain used was a Pioneer hybrid corn previously dried to 11.3 percent moisture in a continuous-flow, LP-fired dryer. This corn was passed through a 11-mm (28/64-in.) round-hole sieve and over a 7.1-mm (18/64-in.) round-hole sieve for cleaning before use.

The shape of the disturbed region was defined by inserting from the bottom, midway between the bin ends, a 6.3-mm (1/4-in.) thick Plexiglas sheet after the auger passed through the grain. This sheet was placed perpendicular to the auger path. Insertion of this sheet and removal of corn from half of the bin permitted observation of the pattern of disturbance caused by the auger. The outline of this disturbed region was traced on the Plexiglas sheet with a grease pencil. Layers of kernels marked with spray enamel paint were

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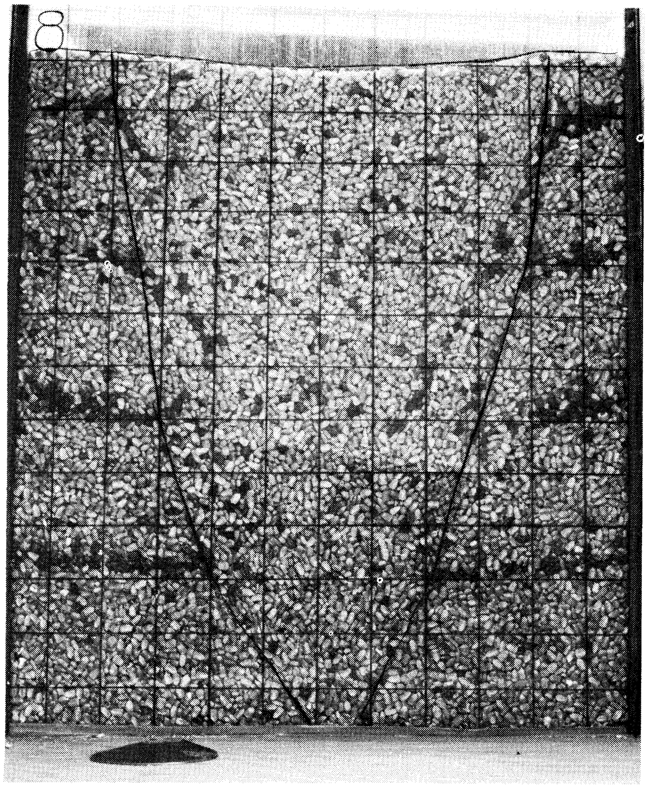

FIG. 1 Disturbed volume cross section for 3.69 mm/s (8.71 in./min) horizontal travel rate. Squares are 51 mm (2 in.) on side.

placed at 150-mm (6-in.) depth intervals during filling to facilitate defining the disturbance region. These marked layers were placed without the 2.1-m (7-ft) drop.

BOUNDARIES OF DISTURBED VOLUME CROSS SECTION

Fig. 1 shows outlined disturbance patterns for an auger travel rate of 3.69 mm/s (8.71 in./min). The stirring auger travelled through the grain in a direction toward the viewer. Disturbance patterns at all speeds were generally parabolic is shape.

Coordinates of points on the outline at 25-mm (1-in.) horizontal intervals were recorded, and least-squares equations fitted through them. Fig. 2 shows the points, curves and equations for the 3.69-mm/s (8.71-in./min) auger travel rate. Variability among test replications tended to increase with auger travel rate and the dividing line between the disturbed and undisturbed regions became more difficult to define. At each nonzero travel speed, there was assymetry between the two halves of the disturbed volume cross section. Facing in the direction of auger travel, the half on the right averaged 10 percent larger area for the three highest travel rates. The left half was 6 percent larger on the 1.84-mm/s (4.35 in./min) cross section. This is apparently an effect of auger rotational direction.

The width of the disturbed region (and hence the cross sectional area disturbed) tended to decrease with increasing auger travel rate. This relationship is shown in Fig. 3. The areas, which were determined graphically, are expressed as area per unit final grain depth because grain depths varied over a range of approximately 100 mm (4 in.) in the tests. An F-test showed the sum of squares about the model to be significantly less than the sum of squares about the mean at the 5 percent probability level.

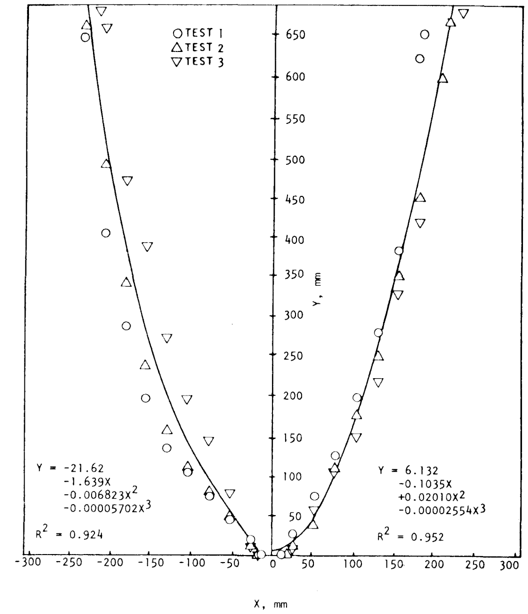

FIG. 2 Shape of disturbed volume cross section for an auger travel rate of 3.69 mm/s (8.71 in./min) in corn in a test bin.

Grain volume was measured before and after each stirring test; grain mass was measured before each test. Stirring always increased the grain volume. The assumption was made that grain outside the outlined disturbed region was undisturbed and that the side boundaries of the disturbed cross section remained the same over the entire bin length traversed by the stirring auger. The volume of the disturbed grain was assumed to increase by the amount of the volume change of the entire grain mass. From grain mass, bin dimensions, cross-sectional area of the disturbed region, and the initial and final grain volumes, computations were made of the original and final bulk densities of the disturbed grain.

The relationship between bulk density decrease and auger travel rate is shown in Fig. 4. The bulk densities before stirring for the 13 tests ranged from 776 to 797 kg/m³ (48.4 to 49.7 lb/ft³). A t-test was run to test the null hypothesis that the slope of this line equals zero. At the 5 percent probability level, the data do

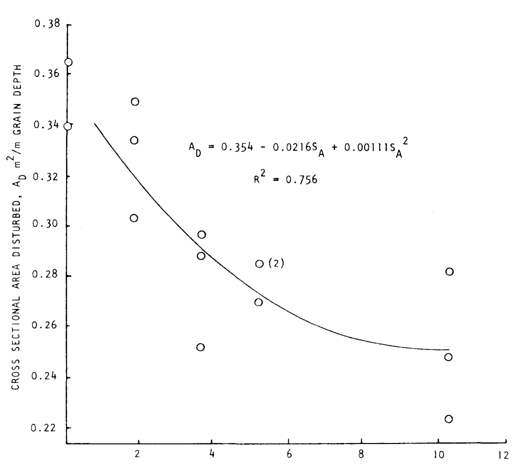

FIG. 3 Cross sectional area disturbed as affected by stirring auger travel rate.

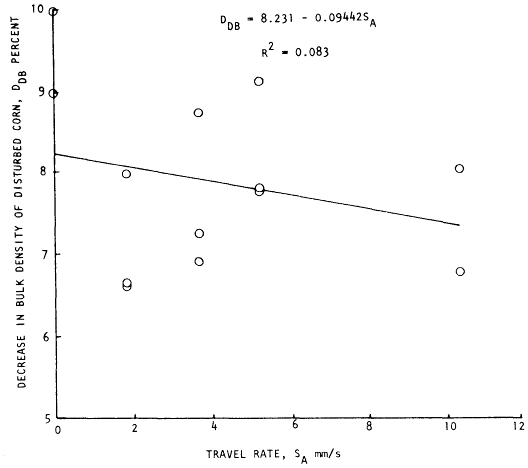

FIG. 4 Percent decrease in bulk density of disturbed corn as affected by auger travel rate.

not show the slope to be different from zero. The magnitude of the bulk density change of the corn disturbed thus was not shown to be dependent on the travel rate of the auger moving through the grain. This bulk density change, which averaged 7.9 percent for the 13 tests, decreases the airflow resistance of the grain (Bern and Charity, 1975).

Fig. 5 shows the relationship between auger travel rate and rate of volume change of the total grain mass. The rate of volume change increases with auger travel rate. Fig. 6 shows the cross-sectional area change of the grain mass as affected by auger travel rate. This change is the cross-sectional area of the continuous mound formed by the stirring auger as it moved through the grain.

All of the grain within the outlined disturbance regions was assumed to be disturbed. This cross-sectional area multiplied by the auger travel rate is the volume rate of grain disturbance. The effect of auger travel rate on the volume rate of grain disturbance is

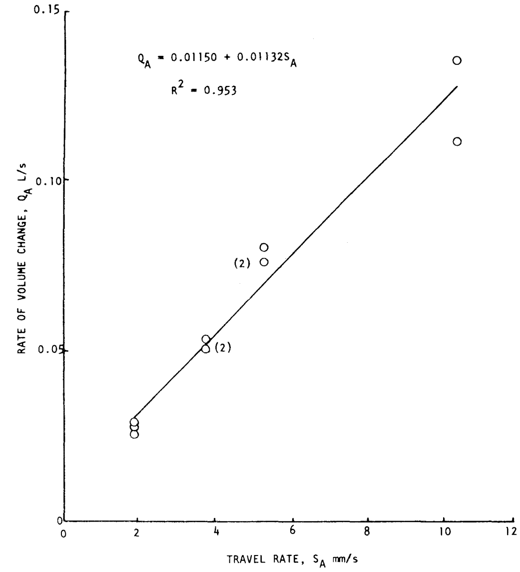

FIG. 5 Rate at which corn volume changed as affected by stirring auger travel rate.

shown in Fig. 7. Because grain depths varied over a range of approximately 100 mm (4 in.) in the tests, rate of grain disturbance is expressed per unit grain depth.

CORN KERNEL ORIENTATION

Fluid flow resistance of non-symmetrical granular material is dependent on particle orientation (Fan, 1959). An experiment to investigate if corn kernels within the disturbed region have a different orientation than kernels in the undisturbed region was conducted during one of the three 1.84-mm/s (4.35-in./min) auger travel rate tests.

All kernels visible through the inserted Plexiglas sheet were designated as pointing up, pointing down, or horizontal. If the kernel tip was higher than the center of the butt, the kernel was counted as pointing up. If the tip was lower, the kernel was counted as pointing down. Kernels for which a slope could not be discerned were counted as horizontal. Of 5662 kernels examined,

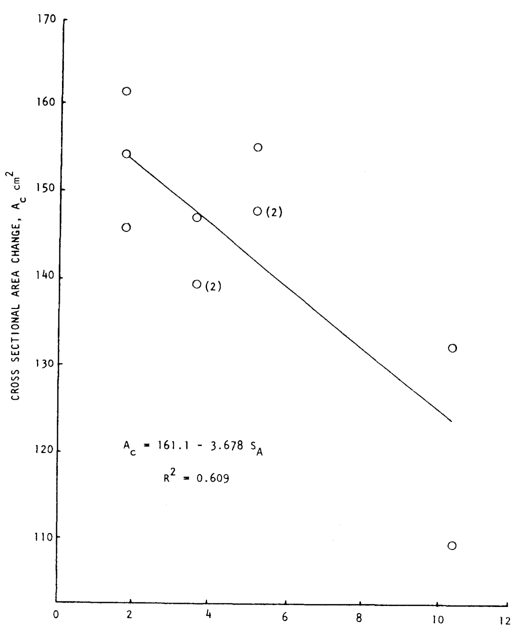

FIG. 6 Change in cross sectional area of corn mass due to stirring as affected by auger travel rate.

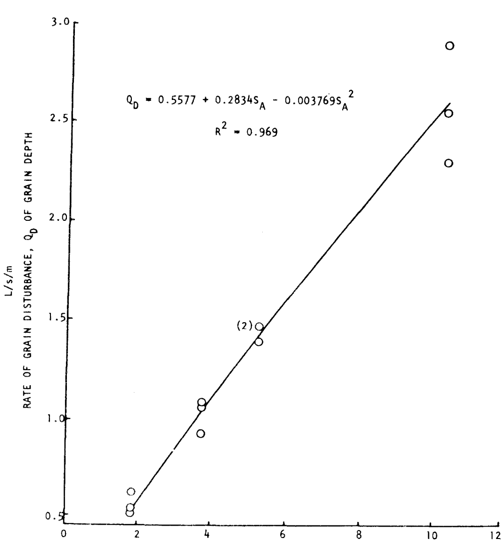

FIG. 7 Volume rate at which corn was disturbed as affected by stirring auger travel rate.

52 percent pointed up, 41 percent pointed down and 7 percent were horizontal.

A statistical analysis was carried out to test the null hypothesis that kernel orientation is the same within and outside the region disturbed by the stirring auger. Using chi square, χ^2, as a test statistic, the null hypothesis must be accepted at the 5 percent probability level, and we must conclude that kernel orientation is the same within and outside the boundary of the area disturbed by the stirring auger.

In this investigation, there is a possibility that the disturbance inserting the plastic sheet destroyed existing differences in kernel orientation. Most of the kernels observed were in contact with the Plexiglas sheet and possibly could have been reoriented during insertion.

CONCLUSIONS

1 The boundaries of the cross-sectional area disturbed by a stirring auger are generally parabolic in shape and can be described by third-degree polynomial equations. This cross-sectional area decreases with increasing auger travel rate.

2 Auger stirring was found to decrease the bulk density of the corn disturbed by about 7.9 percent. Data from this experiment did not show the decrease in bulk density to be dependent on auger travel rate.

3 The rate of grain volume change and the volume rate of grain disturbance increase with auger travel rate.

4 Kernel orientation within the region disturbed by a stirring auger is not significantly different from kernel orientation outside the disturbed region for the kernels visible through an inserted Plexiglas sheet.

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